THE VARIATION OF APPARENT CAPACITY OF A CONDENSER WITH THE TIME OF DISCHARGE AND THE VARIATION OF CAPACITY WITH FREQUENCY IN ALTERNATING CURRENT MEASUREMENTS.

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IT has been known that the impedance offered by a condenser to the passage of an alternating current depends upon the frequency of the current. The capacity is larger for low frequencies than for high, but the amount of this variation was not so generally known. A writer in the *American Telephone Journal* for September 29, 1906, stated that the paper condensers ordinarily used in telephone circuits often fall 50 per cent. below their rated capacity, and that the capacity varies greatly with the frequency of the current applied. The manufacturing companies only warrant an accuracy of 10 per cent. for apparatus of this kind, so a slight change of electrical constants with frequency is not a very serious matter — a dirty plug or a bent spring might make more difference in speech transmission than a small change in inductance or capacity in the circuit. It is of considerable importance, however, to be sure that a condenser rated at 2 M.F. really has that capacity and not merely half that amount. Several months ago Mr. Anthony Zeleny showed that the apparent capacity of a condenser, determined by the ballistic method, depended upon the period of the galvanometer, that is, upon the time during which the discharge of the condenser was to affect the needle or coil of the instrument. I decided to study the behavior of several condensers both with reference to their straight discharge and their capacity when a part of an alternating current.

For this purpose there were at hand six condensers of different kinds. They were, as designated below: (1) a Leeds and Northrup standard mica condenser of 1 M.F. capacity; (2) a Queen and

Company's paper condenser of 1 M.F. capacity; (3) and (4) telephone condensers of one firm rated at 2 M.F. capacity; (5) a telephone condenser of another firm rated at 2 M.F. capacity, and a sixth made by the same firm as (3) and (4) but of so low insulation resistance that no results could be obtained with it.

The straight discharge was first studied, the method being to charge the condenser for 20 seconds and then, after a period of insulation of about .07 second to connect to the ballistic galvanometer for times varying from .0001 second to 11 seconds, the quarter period of the galvanometer. To measure the times of connection with the galvanometer, two pairs of keys, a make- and a break-circuit key in each pair, were made and mounted on heavy maple blocks faced with ebonite. These keys were very similar to those ordinarily used in such experiments and described in the texts on electrical measurements, and so need not be described in detail here. Instead of the heavy pendulum ordinarily employed to release the keys, I mounted a 7/8″ cold drawn steel rod in a vertical position near a strip, also vertical, upon which the keys were mounted. A weight sliding upon this rod struck the triggers and released the keys. The positions of the triggers were determined by means of a fine cathetometer. The friction of the weight upon the rod was first carefully determined and taken into account in computing the time between the setting off of the two triggers. The break-circuit key on each block was provided with a screw by which it could be moved with reference to the make-circuit key by very small amounts. The zero setting was approximated by finding a place where there was no throw of the galvanometer when the weight was released, but, if the breaking key was moved downward by the smallest possible amount, a throw was observed. Settings agreeing to 1/6,000 of a second could thus be made. This does not represent the accuracy of the apparatus but the smallest distance through which the fingers could turn the screw. A series of readings was now taken. The condenser was first allowed to charge for 20 seconds. The weight was then released and, in its fall, broke the charging circuit, and, after .067 second struck the triggers, first connecting and then disconnecting the condenser and the galvanometer. The times of connection were plotted as abscissæ and the corresponding throws of the galvanometer as ordinates. The curve thus obtained was produced back across the axis of times and the point where it cut this line was taken as the true zero point.

The galvanometer was a Leeds and Northrup type P d'Arsonval. It had a resistance of 127 ohms and an inductance of .0014 Henry. The coil was loaded with two small bullets so that its period was 43.08 seconds.

The behavior of the four condensers which were tested is shown, for times up to .01 second in the figures. Curve I. in the first figure is the theoretical discharge curve for the capacity of one microfarad and the corresponding curve of the second figure is the theoretical curve for the capacity of two microfarads. Curves II. and III., Fig. 1, refer to the Leeds and Northrup mica condenser and the Queen paper condenser respectively. With the former the effect

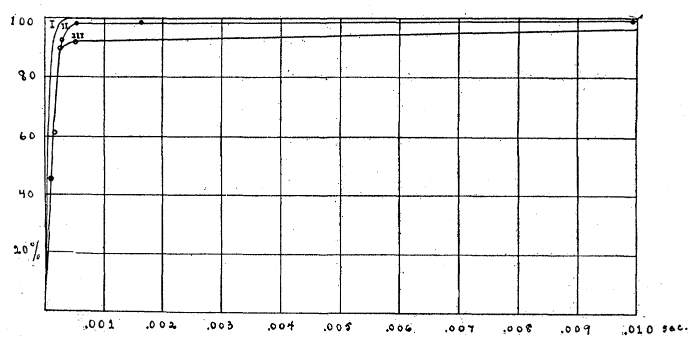

Fig. 1.

of absorption is over in a very short time but, even here, the galvanometer must have a period of at least 5 seconds if the complete charge is to be liberated. Using a Kemp's key with the ballistic galvanometer, the calculated capacity of this condenser was 1.0328 M.F. With the paper condenser the throw, after 8 seconds connection, is still 2 per cent. below that obtained with the Kemp's key and the capacity calculated from this full throw was 1.0519. These values may seem absurdly high, especially for so fine a piece of apparatus as the mica condenser; but these same condensers have been used repeatedly for the determination of the earth's horizontal component H and the value of this constant was uniformly lower than that obtained by Gauss' method, by an amount corresponding to the excess of capacity just shown in the condensers. From the results obtained in the alternating current measurements, the mica condenser appears to be very accurate and the fault is with the ballistic method of measuring the capacity.

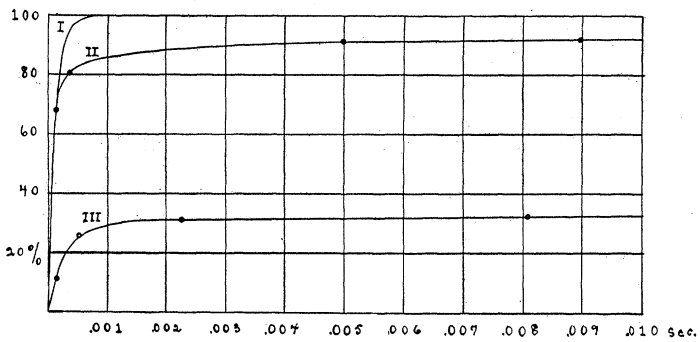

Fig. 2.

Curves II. and III. of the second figure refer to condensers (3) and (4), both being 2 M.F. paper telephone condensers. The capacity of a given condenser of this type increases, of course, with the amount of pressure applied in the making, while the insulation resistance decreases. That designated as (3) is of high resistance and is what they rate as a "hard" condenser; (4) is a medium, while the sixth one referred to in the beginning of this paper as giving no proper result at all, is called "soft." No. 3 appears to be a very good condenser of its class but (4) has parted with only about half of its charge at the end of .01 and is found to continue discharging for two minutes or more.

For determining the capacity of the condensers by means of alternating currents, it seemed best to use some method of comparing their impedance with that caused by a self-induction; for, even if there should be a small error in the value assumed for the latter, the data sought, namely, the variation of capacity with frequency, will be as valuable as ever. The coil used as a standard of inductance was of No. 23 copper wire, insulated with silk and wound upon a marble cylinder. Its inductance was .011316. For such a coil the effect of frequency upon resistance and inductance, for frequencies up to 3,000, is too small to be taken into account here. After trying several of the standard arrangements for comparing a capacity to an inductance a modification of Anderson's method was used. This involved the fewest assumptions and will allow a large number of measurements to be made in rapid succession. The arrangement shown in Fig. 3 is the common one except that, by means of a double key, each half having six points, a battery and a galvanometer, or a source of alternating current and a receiver, may be connected to the points of the bridge by merely throwing the lever. Leaving the key in the normal position, as shown in the figure, one may adjust the arms of the bridge for a direct-current balance and then, throwing the key into the other position, adjust the resistance r till the sound in the receiver is a minimum. The capacity is now given by the equation

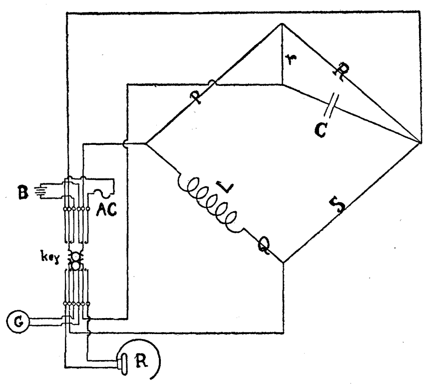

Fig. 3.

$$C = \frac{L}{r(Q+S)+PS}.$$

To secure alternating current of varying frequencies up to 3,000, which was sufficiently high to represent ordinary voice currents, a small inductor-alternator was constructed. It consisted of an ebonite disk having about its circumference 60 soft iron, cylindrical inductors .25 in. in diameter, rotating between the poles of the field magnet. The armature coils were wound upon these poles. As the whole effect found was small, no account was taken of wave-form. For the very low frequencies (16 and 66) the currents from a pole-changer were used.

The results thus obtained are shown in the following table:

Numbers 1, 2 and 3 increase very slightly in capacity between 16 (or 66) and 125 cycles per second. The other two do not show this increase but all fall off regularly up to the highest frequencies

Condenser.	Capacity (Ball).	Frequency.	Capacity.	Per Cent. Loss.
1	1.0328	66	0.9961	
		125	0.9970	
		1,450	0.9951	
		2,945	0.9931	0.4
2	1.0519	16	0.9985	
		125	1.0005	
		1,360	0.9965	
		3,020	0.9901	0.8
3	2.170	16	2.0328	
		125	2.0367	
		990	2.0245	
		3,040	2.0064	1.49
4	2.170	16	1.8519	
		125	1.8519	
		1,350	1.8379	
		3,050	1.8046	2.55
5		16	2.3448	
		125	2.3420	
		1,350	2.3231	
		3,000	2.3066	1.10

tried. The worst, however, decreases but 2.55 per cent., which is an amount too small to be of account in considering their effect upon speech currents. As the frequency rises, the minimum of sound in the receiver becomes less marked in all cases. With the poorer paper condensers, this is true to such an extent that no very exact adjustments could be made, but the capacity of these condensers was somewhat indefinite.

It will be seen by comparing the discharge curves of the several condensers with their alternating-current capacities as given in the table, that the latter cannot be inferred from the former. Taking condenser No. 4, as an example, it will be seen that, up to .01 second, the capacity is only about 37 per cent. of that obtained when the condenser was allowed to discharge for the whole quarter period of the galvanometer. With an alternating current, however, in which the period of charge — that is, the quarter-period of the complete oscillation — was only .00008 second, the capacity was still 80 per cent. of that obtained by the ballistic method and the complete quarter-period of the galvanometer.

CHICAGO,
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